An Unusual Two-Higgs Doublet Model from Warped Space

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Outline

The Elevator Talk

Overview

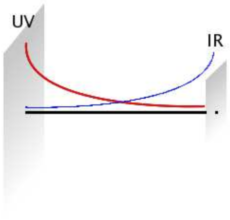
1. $t\bar{t}$ condensation in RS
2. Two Higgs Doublet Model
3. Move Q_{3L} away from IR brane
4. Ease EWPO constraints.

Randall Sundrum Models

The Bare Essentials

RS Models are 5D theories with a non-trivial warped geometry.

$$ds^2 = e^{-2k|y|} dx^\mu dx_\mu - dy^2.$$



- SM states are zero modes of five dimensional fields;
- Higgs, Fermions and KK modes are localized in XD.

Electroweak Constraints and $Z \longrightarrow b\bar{b}$

4D interactions depend on 5D wavefunction overlaps.

$\Longrightarrow$ KK modes couple strongest to t_R, Q_{3L}.

$\Longrightarrow$ Large corrections to SM predictions for these states.

Relevant LEP constraints:

- T-parameter;
- $Z \rightarrow b\bar{b}$.

Solve these problems by:

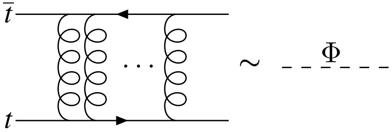
- Gauging $SU(2)_R$;
- Adding a P_{LR} symmetry.

Can also ease constraints by moving Q_{3L} away from IR brane.

This was our Goal.

Composite Higgses in RS

KK gluon mediates strong top-sector interactions.



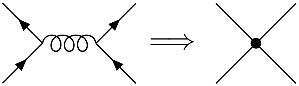
Extra Higgs $\Longrightarrow$ extra contribution to m_{top}
$\Longrightarrow$ move Q_{3L} away from IR brane.

Earlier ideas:

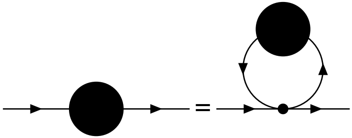
- Using exotic fermions; or
- Using high (30 TeV) KK scale; and
- No fundamental Higgs.

The Gap Equation
NJL Models

Integrate out KK gluon:



Generate mass term non-perturbatively:



Non-trivial statement about strong dynamics!

The Two Higgs Doublet Model
An analytic approach

Can show: Gap equation solved $\Rightarrow$ Scalar field in spectrum.

Rewrite NJL four-fermion term using auxillary scalar:

$$\frac{g}{M_{KK}^2}\left(\bar{\Psi}\Psi\right)^2 = M_{KK}^2\Phi^2 + g\Phi\bar{\Psi}\Psi.$$

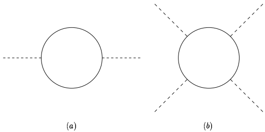
Model parameters:

1. Fundamental scalar parameters λ_0, m_0;
2. KK Gluon mass M_{KK};
3. Scalar-Fermion couplings g_t, λ_t—depend on 5D fermion localization.

NO new parameters compared to RS!

Physics Below the KK Scale
RGEs

Renormalisation of fields below KK gluon mass:



Generates:

1. Kinetic term for Φ;
2. Sizeable kinetic mixing between H, Φ;
3. Mass mixing between H, Φ;
4. All possible quartic terms.

Diagonalising the Kinetic Sector

Need to:

1. Remove kinetic mixing;
2. Bring kinetic terms to canonical normalisation.

Accomplish these goals with the field redefinition:

$$H = \hat{H}$$
$$\Phi = -\frac{\lambda_t}{g_t}\hat{H} + \frac{1}{g_t\sqrt{\epsilon}}\hat{\Phi}$$

Leads to very simple Lagrangian:

$$\mathcal{L}_{int} = M_{hh}^2 \hat{H}^\dagger \hat{H} + M_{h\Phi}^2 \left(\hat{H}^\dagger \hat{\Phi} + \hat{\Phi}^\dagger \hat{H}\right) + M_{\Phi\Phi}^2 \hat{\Phi}^\dagger \hat{\Phi} + \frac{1}{2}\lambda_0 (\hat{H}^\dagger \hat{H})^2 + \frac{1}{\epsilon}(\hat{\Phi}^\dagger \hat{\Phi})^2 + \frac{1}{\sqrt{\epsilon}}\overline{Q_{3L}} t_R \tilde{\hat{\Phi}} + h.c.$$

Matching to the Standard Model

Low Energy Boundary Conditions

In our model, both Higgses acquire a vev.

$\Longrightarrow$ CP, $U(1)_{em}$ are automatically conserved.

Matching to SM:

1. Match EWSB: $v_{ew}^2 = v_H^2 + v_\Phi^2$.
2. Match top quark mass: $m_t = \frac{v \cos\beta}{\sqrt{2\epsilon}}$.

This determines both vevs!

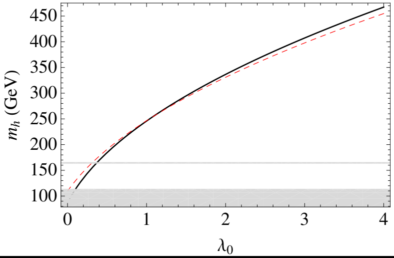
The Scalar Spectrum
The Decoupling Limit

Neglecting mass mixing, scalar potential has symmetry

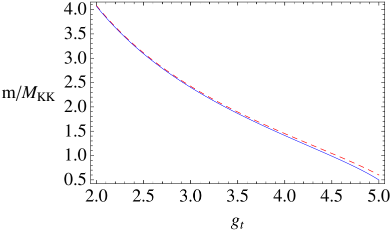
$$SU(2)_{\Phi L} \times SU(2)_{\Phi R} \times SU(2)_{HL} \times SU(2)_{HR}.$$

Vevs break this to $SU(2)_{\Phi D} \times SU(2)_{HD}$; mass mixing to $SU(2)_V$.
$\implies$ Implies degeneracy of $H^{\pm}$, A^0 ($SU(2)_V$ triplet).

Light, SM-like scalar



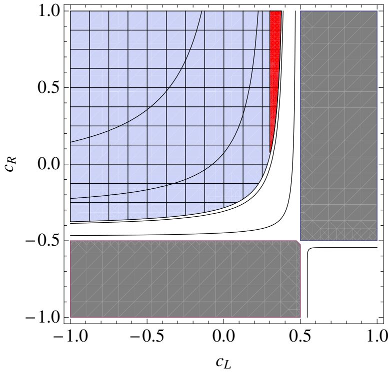
Heavy, decoupled scalars

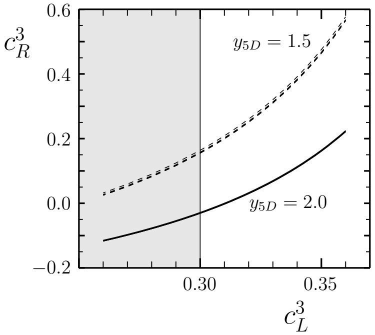


Numerical Results
RS Lagrangian Parameters

Regions exist where P_{LR} is unnecessary!

Region where top condensation occurs is large!





Flavour-Changing Neutral Currents

Or, How I Learnt to Stop Worrying and Love My Model

Won't this model lead to tree-level FCNCs?

Yes.

Yukawa sector:

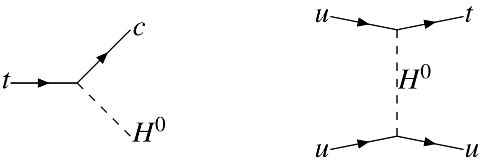
$$\mathcal{L}_Y = -\frac{\sqrt{2}\mathcal{M}^d_{ij}}{v \sin\beta}\,\overline{Q_{Li}}\,d_{jR}\,\hat{H} - \frac{\sqrt{2}\mathcal{M}^u_{ij}}{v \sin\beta}\,\overline{Q_{iL}}\,u_{jR}\,\widetilde{\hat{H}} + \frac{1}{\sqrt{\epsilon}}\,\overline{Q_{3L}}\,t_R\left(\widetilde{\hat{\Phi}} - \frac{\widetilde{\hat{H}}}{\tan\beta}\right) + h.c.$$

Suppression factors:

- Light Higgs: $\sin(\alpha-\beta) \approx 10^{-3}$;
- Heavy Higgs: M_{KK}^{-1};
- Small Mixing Angles: $\overline{Q_{3L}}$, t_R mostly top.

Unusual Top Production and Decay

Our model predicts FCNC production, decay of top quark:



What will these look like at the LHC?

TeVatron has measured 2σ discrepancy in top A_{FB}.

$$A_{FB}^{exp} = 0.193 \pm 0.065 \pm 0.024; \qquad A_{FB}^{SM} = 0.050 \pm 0.015.$$

$\Longrightarrow$ Can our model say anything about this?

Summary & Conclusions

1. Formation of a composite scalar doublet is quasi-generic in RS models.
2. The resultant 2HDM eases some of the constraints.
3. Flavour-changing top physics expected; other FCNCs probably small.